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THESIS

OPTIMIZATION OF SEALIFT SHIP TYPES IN THE READY
RESERVE FLEET (RRF) AND MARITIME PREPOSITIONED
SHIP (MPS) FLEETS

by

Robert K. Briede

June, 1990

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Francois Melese

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Optimization of Sealift Ship Types in the Ready Reserve Fleet (RRF)
and Maritime Prepositioned Ship (MPS) Fleets

by

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Submitted in partial fulfillment
of the requirements for the degree of

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I. ABSTRACT

This thesis examines a method for optimizing the effectiveness of existing sealift fleets given a limited budget. A brief background of U.S. military mobility is presented. Relevant cost categories of the Ready Reserve Force (RRF) and prepositioned forces are determined by looking at the life-cycle of sealift ships. A methodology for determining an optimal fleet mix is presented. Two models for optimizing the direct costs of mobilizing the RRF and prepositioned forces are developed. The first model is based upon a single trip to the war zone. The second model develops the possibility that sealift ships may make multiple trips to the war zone and return to U.S. seaports. Methodologies for determining an optimal fleet mix are presented.



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I. INTRODUCTION

A. BACKGROUND

The United States provides war materials to a war zone using three methods: (i) military airlift, (ii) the use of prepositioned stocks, and (iii) military sealift ships. The three methods are commonly referred as the mobility triad. The two ways in which sealift transports materials to a war zone are via Ready Reserve ships and by prepositioning ships. Ready Reserve Force (RRF) ships are stationed at various locations within the continental United States while Maritime Prepositioned Ships (MPS) are located in the vicinity of the most likely war zones.

To date, the 104 ships within the Ready Reserve Force have been purchased by the U.S. and stored for possible use in transporting war materials. Upon notification of an impending conflict, RRF ships are brought out of storage and made operational. War stocks are then loaded on to the ships and the ships are then sailed to the theater of conflict.

The United States uses 13 Maritime Prepositioned Ships located near strategic areas of operations to provide a timely surge of war fighting equipment. These ships are fully stocked to provide war fighting material and 30 days of supplies for a Marine Amphibious Battalion (about 16,500 men).

B. OBJECTIVE

The objective of this thesis is to develop models and procedures in order to make better use of the Ready Reserve Force

and prepositioned forces under budgetary constraints. More specifically, given a crises, what is the priority of ship activation for the expected sealift operation. Two models are developed. The first model develops an optimization framework for choosing a fleet of sealift ships that perform a single trip to the war zone during a crisis. The second model takes into consideration the possibility that the sealift ships may have to make numerous trips during a crisis. The models are developed so that policy makers can examine trade-offs regarding speed, capacity, and budgets.

C. RESEARCH QUESTIONS

The primary research question is whether a model can be developed that can guide the use of sealift forces in time of crisis. Secondary questions include: what are the relevant costs of the RRF?, what are the relevant costs of the prepositioned forces?, and how can the best mix of ships be determined given the trade-off of speed and capacity and the preferences of policy makers?.

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

1. Scope

The scope of the paper is restricted to the development of models for Ready Reserve Force (RRF) ships and Maritime Prepositioning Ships (MPS). Airlift was not addressed because it performs a different mission. Airlift delivers a variety of surge equipment, emergency equipment, and the personnel to fight a war. Sealift provides the vast majority of equipment that will be used

in a conflict including surge requirements, but mainly sustaining equipment.

2. Limitations

One of the limitations of the model results from the accounting practices of the Maritime Administration (MARAD) and the Strategic Sealift Command (MSC). Costs are tracked by budget category (i.e. Operations and Maintenance, Shipbuilding and Conversion etc.) and not by ship categories and age. The level of detail of cost data was broader than what is required by the model. However, development of the model suggests that significant benefits could be associated with the collection of data by ship category and age.

Another limitation was that no studies were discovered with a similar scope in an extensive review of the literature. The available literature tended to focus either on a review of military sealift capabilities and programs or on specific linear programming and transportation problems.

3. Assumptions

A primary assumption is that the size of military sealift fleets will not decrease, but may increase in the future. Another assumption is that indirect costs will not significantly effect the results of the analysis (although future studies might relax this assumption). It is implicitly assumed that indirect costs will not vary significantly with marginal changes to current sealift capabilities. Another assumption is that the marginal rate of substitution is a linear function that does not change with changes

in the levels of attributes (Chapter 5, Section E). Finally, the endurance of sealift ships was assumed not to be a factor in the decision of policy makers when selecting between ships of high speed and low capacity or low speed and high capacity. It is assumed that the endurance of both types of ships is adequate.

E. LITERATURE REVIEW

The literature that was surveyed and examined to produce this paper includes the history and background of military mobility by various military and civilian authors, the Navy's Strategic Sealift Division (OP-42), various masters theses, and military and trade magazines. Cost information was derived from studies done by the Center for Naval Analysis (CNA), the Naval Audit Service, and documents received from the Maritime Administration, the Department of Defense, and Rana Corporation. The economic analysis came from economics text books, and papers in various economics journals.

F. ORGANIZATION

The study begins with background information about military mobility. The concept of operations of airlift and sealift are examined. Next, an optimization model is developed for the Ready Reserve Force and prepositioned ships. This model is based upon sealift ships making only one trip to the war zone. A second model in which sealift ships would make multiple trips to the war zone is included next. Finally, a conclusion and summary are provided. A typical sealift scenario is developed and placed in the appendix. This scenario could be useful as a baseline in the future implementation of the models developed and is used in an example.

II. BACKGROUND

A. SCOPE

The military strategy of the United States emphasizes forward deployment for deterrence and the forward engagement of potential aggressors on a global basis. [Ref. 1:pg. 1] This strategy requires that war materials be prepositioned in forward areas, and that there exists a capability to transport materials, equipment, and combat personnel to the theater of war. In the United States strategic mobility consists of a triad of sealift, airlift and prepositioning to deploy and sustain U.S. forces overseas. As shown in Figure 1, each of the mobility elements is interdependent and each has its advantages and disadvantages.

Sealift is a basic responsibility of the Department of the Navy. The Navy's sealift capability is designed to transport very large quantities of heavy equipment, ammunition, fuel, and supplies for sustained operations overseas. Airlift is the responsibility of the Department of the Air Force. Airlift capability is designed to transport combat personnel and small quantities of heavy equipment. While sealift has greater transport capability, airlift is able to transport in much less time. At-sea prepositioning is a joint responsibility of all the services. The concept of at-sea prepositioning is to hold heavy equipment, ammunition, food stuffs, water, lubricants, and supplies on-board various cargo ships. The

cargo ships are then located or anchored near a possible war theater until needed. [Ref. 1:pg. 1]

	<u>ADVANTAGES</u>	<u>DISADVANTAGES</u>
AIRLIFT:	FAST FLEXIBLE (cargo can be changed quickly)	LIMITED CAPACITY AIRFIELD DEPENDENT
SEALIFT:	LARGE CAPACITY SOME FLEXIBILITY	SLOW SEAPORT/SEALANE DEPENDENT
PREPOSITION:	FAST REDUCES SHIP MOVEMENT (less vulnerable)	REQUIRES MARRY-UP LACKS FLEXIBILITY

Figure 1. The Mobility Triad

B. SOURCES OF MILITARY MOBILITY

1. Military Sealift

a. Scope

On 13 March 1984 the Secretary of the Navy, John Lehman, designated strategic sealift as a distinct Navy function. [Ref. 1:pg. 1] In clarifying this role, the Chief of Naval Operations, Admiral Watkins, defined strategic sealift as "The afloat prepositioning and ocean movement of material, petroleum, oil and lubricants, and personnel in support of assigned logistic support missions of the U.S. government, including the necessary cargo handling systems and personnel to ensure delivery of cargo ashore." This scope has been broadened to include the needs of the

Air Force and Army and to ensure multi-service compatibility. [Ref. 1:pg. 1]

b. Concept of Operations

Strategic sealift for mobility of forces includes three major categories of shipping: prepositioned, surge, and resupply. [Ref. 1:pg. 3] The three categories of shipping provide two broad types of equipment: unit equipment and sustaining supplies. Prepositioned equipment is to be delivered rapidly to the theater of operations; usually within days. The concept of prepositioning is to load military equipment and supplies on board ships and then preposition the ships near a contingency area. Should a conflict occur in the region, these ships are sailed to the war theater and "married" to the incoming airlifted personnel. Surge shipping is relied on to transport most equipment and supplies to the war theater from the continental United States. Surge equipment arrives after prepositioned material and continues to be stocked until there is enough war material to fight as directed. Resupply equipment immediately follows the surge equipment to sustain combat operations. [Ref. 1:pg. 4]

Figure 2 shows the timing of each major category of strategic shipping and the type of equipment that each provides. Surge shipping brings all war-fighting equipment and supplies to the area of operations that are not delivered by prepositioned ships. Surge shipping rises and then falls after directed equipment

levels reach the war theater. Resupply shipping provides all equipment and materials that are needed to sustain forces provided by surge shipping. Resupply shipping rises as force levels rise and then tapers off as directed force levels are achieved. [Ref. 1:pg. 4]

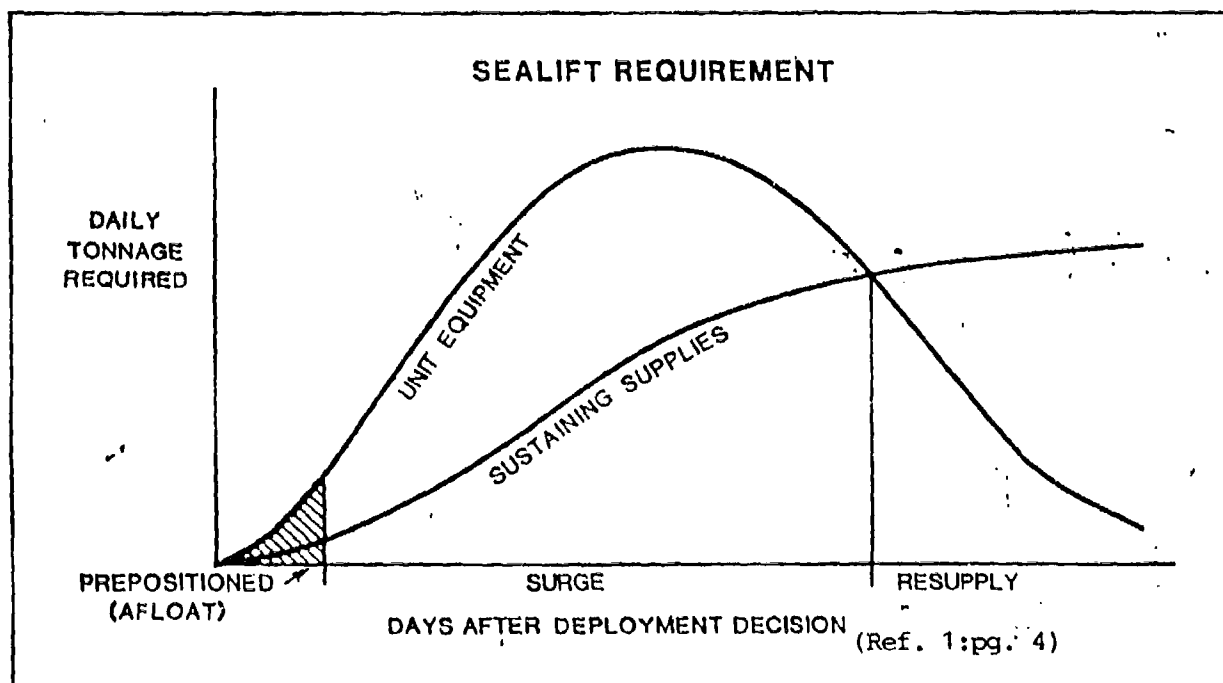


Figure 2. Timing of Shipping Channels

c. Strategic Sealift Assets

(1) *Prepositioned Ships.* There are two prepositioned forces, the Maritime Prepositioned Force and the Afloat Prepositioning, both of which come under the control of the

Military Sealift Command. The Afloat Prepositioning Force is made of 23 ships of various types including breakbulk ships, container ships, and tankers. Breakbulk ships are cargo ships with multiple hatches and holds, fitted with booms or cranes for self-sustaining load/discharge. Prepositioning ships are loaded with combat supplies such as ammunition, fuel, water, and lubricants in support of all U.S. services. [Ref. 2:pg. 10]

The Maritime Prepositioning Force consists of 13 ships operated under long term contracts (25 years) by civilian shippers. A civilian long term contract was considered necessary to help maintain a base of merchant seamen in the United States. These ships carry a varied load of equipment, fuel, food, water, and other supplies for the U.S. Marine Corps.

The ships are divided into three squadrons anchored separately in U.S. areas of interest: Middle East/Indian Ocean, North Atlantic/Europe, and South-East Asia/Korea. [Ref. 3] Each squadron carries sufficient equipment and supplies to sustain a U.S.M.C. Expeditionary Brigade of 16,500 men for thirty days of combat.[Ref. 2:pg. 10] The on-board equipment and supplies are regularly maintained by U.S. service personnel, while the ships are maintained by civilian shippers. Every ten years the ships are rotated to the U.S. for unpacking, inspection, maintenance and repacking.[Ref. 3]

(2) *Ready Reserve Force.* The Ready Reserve Force (RRF) consists of a variety of types of military capable merchant vessels and special purpose ships. The ships are kept in reserve under the Maritime Administration (MARAD) which is the government organization concerned with ocean going activities. MARAD is part of the Department of Transportation. The ships, which were commercially less useful, were individually selected on the basis of significant remaining steaming life. Ready Reserve ships are maintained so that they can be activated and manned for operations in 5, 10, or 20 days at designated shipyards without dry docking. [Ref. 2:pg. 10] The requirement to activate a ship without dry docking significantly reduces the time needed to make a ship operational.

(3) *Fast Sealift Ships.* The United States has a fast sealift program consisting of eight high speed SL-7 container ships subsequently converted for rapid load, transport, and off-load of Army combat equipment. [Ref. 3] The ships are operated by commercial shipping companies under contract by the Military Sealift Command. The ships are berthed on the East and Gulf Coasts and maintained at reduced operational status. Once directed, the ships can be brought to full operational status in four days. [Ref. 1:pg. 23]

d. Other Sealift Assets.

(1) *U.S. Flag Merchant Fleet.* Section 902 of the Merchant Marine Act of 1936, as amended, subjects all U.S. flag vessels to U.S. government requisition in times of mobilization. Approximately 70% of the U.S. flag merchant fleet has been deemed militarily useful. [Ref. 2:pg. 11]

Any U.S. flag vessel which has received federal subsidies is a party to the Sealift Readiness Program (SRP). This program also applies to operators carrying military cargo under MSC contract. Upon mobilization, the SRP program allows these ships to be available to MSC which administers the program. [Ref. 2:pg. 12]

(2) *Effective U.S. Control Fleet.* Effective U.S. Control fleet (EUSC) vessels are U.S. owned, but registered under foreign flags such as Panama or Liberia. The laws of the foreign flags do not preclude or limit U.S. authority to recall these ships in times of declared emergency under Section 902 of the Merchant Marine Act of 1936. These ships are operated by foreign crews of the ship' flag country. Questions have risen concerning the ability to maintain the foreign crews in time of conflict or the ability of the U.S. crew to operate unfamiliar ships. [Ref. 2:pg. 13]

(3) *National Defense Reserve Fleet.* The National Defense Reserve Fleet (NDRF) consists of older merchant ships that have some military utility. These ships are kept at three reserve fleet sites within the United States in various states of

readiness. NDRF ships are much older and usually less capable than Ready Reserve ships.

2. Military Airlift

a. Scope

The Military Airlift Command, (MAC), grew from the post World War II Military Air Transportation Service (MATS) established in 1948. [Ref. 4:pg. 40] In 1977 MAC became a specified command. [Ref. 5:pg. 352] Although the Army and Navy retain a small portion of airlift capacity, MAC is the manager of all U.S. airlift capability and has a substantial resource base. In 1987, MAC consisted of more than 94,000 active duty military and civilian personnel, 1000 aircraft, and over 340 locations in 26 countries. [Ref. 4:pg. 42] MAC routinely supports the logistical needs of all DOD services.

To complement the MAC's organic airlift capacity, the Civil Reserve Air Fleet, (CRAF), was created in 1952. Under the CRAF program, selected U.S. civil aircraft are contracted to augment DOD assets in a state of emergency. [Ref. 4:pg. 44] In 1981 the Air Force submitted a Congressionally Mandated Mobility Study (CMMS). In further defining the role of the Air Force the mobility study recommended that MAC have an airlift level of 66 metric ton miles per day. [Ref. 5:pg. 373] In 1988, airlift capacity was about 40 MTM/day. [Ref. 5:pg. 372] It is expected that the recommended level of 66 MTM/day will be obtained in the

late 1990's with the introduction of the C-17 aircraft. [Ref. 5:pg. 383] Modern airlift capacity has been designed around this lift capacity and four lift scenarios: Persian Gulf, Soviet Invasion of Iran, a NATO/Warsaw Pact conflict, and a conflict in the Persian Gulf Accompanied by a precautionary reinforcement of Europe. [Ref. 5:pg. 371]

b. Concept of Operations

Airlift mobility forces provide a rapid deployment capability of combat units to and within the war theater. Airlift is designed to meet the critical 15 day deployment period identified in the CMMS. [Ref. 5:pg. 368] It is predicted that more than 90% of all materials arriving in the war theater within the first 15-20 days of a conflict will be delivered by air. Long range air operations is performed by C-141 and C-5 aircraft. The other 10% will be delivered by prepositioned ships. [Ref. 5:pg. 368] After 20 days the percent of overall cargo to have reached the war theater by sea will increase. [Ref. 5:pg. 369] Airlift will provide almost all troop transport during a conflict. [Ref. 3] Once the cargo reaches the war theater, inter-theater cargo aircraft such as the C-130 will be used to transport it as necessary within theater. CRAF aircraft are activated in three stages with later stages having shorter response times and larger call-ups. Activation of CRAF is done with full participation of the Department of Transportation. The CRAF is expected to provide more

than 11 metric ton miles per day during times of crises. [Ref. 5:pg. 382]

c. Airlift Assets

(1) *Military Airlift Command*. As mentioned previously, the MAC relies on C-141 and C-5 aircraft for most heavy airlift transport overseas. MAC uses C-9s and C-141s as primary troop transporters. Once inside the war theater a large variety of aircraft are used including the C-130, C-39, C-12, and C-140 fixed wing aircraft along with various helicopters.

(2) *Civil Reserve Air Fleet*. Participation in the CRAF consists of approximately 36 domestic air carriers flying a variety of aircraft including the B-707, DC-8, B-747, DC-10, L-1011, B-767, and the A-310. The CRAF consists of four segments: domestic, Alaskan, short range international, and long range international. [Ref. 4:pgs. 44,45] The long range international fleet augments the MAC's long range C-141 and C-5 aircraft during periods of conflict. [Ref. 5:pg. 382]

C. CONCLUSION

The mobility triad consists of airlift, sealift, and prepositioned forces. The advantages to sealift are the large tonnage capacity and the ability to select a variety of material for each cargo depending upon priorities (flexibility). The disadvantages of sealift are its slow speed and dependence on seaports and sealanes. Two sealift forces, the Ready Reserve Force

(RRF) and the Maritime Prepositioned Ships (MPS) squadrons would provide most of the material mobility in any conflict. This is evidenced by the 1991 Persian Gulf Conflict.[Ref. 6:pg. 10] The following chapter will develop a model for optimizing the activation sealift ships in a time of crisis.

III. SEALIFT OPTIMIZING MODEL

A. INTRODUCTION/SCOPE

In this chapter an optimization model of sealift capability is developed. The model is based on sealift ships making single trips to the war zone and return to U.S. seaports (i.e. no return trips). The chapter begins with a discussion of the objectives of sealift and the factors that should be included in the model. Next, alternative transportation modes are discussed and those beyond the scope of the paper (not the model) are eliminated. The remaining options form the basis of the paper.

Relevant costs are identified by examining the life cycle of a typical sealift ship. Section E introduces the model. Included is a discussion of possible, efficient, and optimal solutions to sealift. Also included is a procedure for selecting an optimal fleet. Section F presents the development of cost and time models for the use in Section E. Next, procedures are defined that lead to the optimization of each alternative. Finally, two examples are included which demonstrate the calculation of the various indices.

B. OBJECTIVE

The objective of military mobility is to get as much of the correct material to the war region as rapidly as possible. Military policy dictates the size of U.S. forces and the equipment

that each service will use. The military services then determine the requirements for Navy sealift ships and Air Force airlift aircraft. U.S. sealift and airlift planners base their analyses on requirements dictated by military policy.

In order to determine the best mix of mobility, some measure of effectiveness needs to be established. The effectiveness of sealift ships and airlift aircraft can be measured by the amount of cargo delivered to the war region in a certain period of time. To compare the effectiveness of the different ships we derive an effectiveness index that takes into consideration the amount of cargo that a ship carries (capacity) and the time it takes to accomplish its mission (speed). Once the effectiveness indices of individual mobility elements are determined, these are combined with cost measures to determine the optimal mix.

C. OPTIONS

In evaluating the alternatives for military mobility, many options arise. This study is aimed at determining the optimal mix of sealift ships. Airlift options are not considered for several reasons. First, the missions of airlift and sealift are different. As explained in Chapter II, airlift is used to deliver surge equipment and troops. Although one role of sealift is to deliver surge equipment through prepositioning, the primary role is to deliver sustaining equipment. Moreover, the cost of purchasing a fleet of aircraft that could deliver sufficient war materials for

a conflict is not economical. [Ref. 7:pg. 48] Sealift, therefore, is intended to deliver 95% of dry cargo and 99% of liquid cargo (petroleum, oil, lubricants, and water). This fact is underscored by recent history in the war with Iraq. In that war, sealift had carried as much to Saudi Arabia on the first two ships than the total airlift deliveries to the theater, in what turned out to be the biggest airlift in history. [Ref. 6:pg. 10]

The need for airlift is not disputed. Slower deployment rates require substantially larger ground and air forces for the initial stabilization and eventual counter-attack after the erupted conflict. [Ref. 8:pg. 18] For example, quick delivery of critical equipment may be essential in preventing an invader of a country from securing ports and airstrips that the U.S. intends to use. Without a policy of significant and early presence, the U.S. would have to operate further from the war front and possibly encounter greater layers of defense. Airlift, therefore, is essential in providing materials for initial operations and insuring the U.S. a supportable position. Differing requirements, though, demand that airlift and sealift be analyzed separately.

Decreasing the existing force levels of the RRF and prepositioned ships is not considered an option. The reason for this is the growing realization that current U.S. military objectives are unattainable without sufficient sealift capability. [Ref. 3] This can be seen in the large increases in money spent on

sealift during the last ten years. Even with the large increases, Vice Admiral Francis R. Donovan Jr., Commander of Military Sealift Command, has stated that the U.S. needs more ships. Specifically he has stated that "RRF readiness must be improved" that "... there aren't enough unit equipment-capable ships" and referring to the Persian Gulf experience that "sustainment requirements would be met with difficulty". [Ref. 9:pg. 12] The remaining options available to the United States are essentially to accept the status quo or to add to existing sealift capabilities. [Ref. 10:pg. 22] Thus the options are:

1. **Option 1: Status Quo** - Optimal use of the existing fleet.
2. **Option 2: Fleet additions** - Growth of the fleet with the addition of ships to either the RRF or the prepositioned forces.

D. COSTS

1. Relevant Costs

The Navy spent over \$7 billion on military sealift from 1980 to 1990. [Ref. 9:pg. 12] The money spent, or the costs associated with sealift, can be broken into several different categories such as direct/indirect, fixed/variable, recurring/non-recurring or total/marginal. All costs are or have been relevant to some decision, past or future. The key is to distinguish the relevant costs for present and future decisions from the irrelevant costs. Relevant costs lie in the future, not in the past. [Ref. 11:pg. 33]

In developing a model to determine the optimal least-cost fleet of sealift ships, only those costs that lie in the future are considered. For example, the acquisition costs of ships currently in the RRF are sunk costs and therefore irrelevant to this study. Alternatively, the yearly maintenance costs of the RRF represent an example of relevant costs. However, the relevance of other cost categories cannot be easily determined. An example of this is indirect costs.

Indirect costs are those not easily associated with the purchase, maintenance or operation of sealift ships. An example of indirect costs is overhead such as support and maintenance facilities. For example, the Department of Transportation, which governs the Maritime Administration, employs thousands of civilian personnel. Similarly, the Military Sealift Command employed approximately 8000 civil service and military personnel in 1987. [Ref. 4:pg. 17] Part of the necessity of each organization's large staff is due to the indirect support of military sealift. Although a part of these costs could be allocated to sealift, in practice such allocation schemes are often arbitrary.

Other examples of indirect costs can be seen in the financial statements of each organization. Overhead expenses of the Military Sealift Command include the cost of computers and software, rent of occupied buildings, maintenance and rental of office equipment, stationary and postage. [Ref. 12:pg. 7]

Because of the difficulty in allocating indirect costs, only direct costs will be used to determine the effectiveness of sealift ships. Indirect costs will not be closely examined in this study, although future studies of military sealift should attempt to include as many relevant indirect costs as possible.

The major costs of sealift can be broken into three groups: recurring costs, non-recurring costs, and contingency costs. Recurring costs are those that occur on a continuing basis such as maintenance. Non-recurring costs are those that only occur once in the lifetime of the ship. The two major non-recurring costs are acquisition and the initial deactivation. Contingency costs are the cost of operating a sealift ship in a crisis. The four main contingency costs are activation, manning, steaming (fulfillment of operational requirements), and re-deactivation. The relevant need to be measured are those that are additional (marginal) sealift costs attributable to each mode of sealift. For instance, the acquisition costs of the RRF should not be considered because they have already been paid and therefore are sunk costs. The acquisition costs of future sealift ships should, however, be considered under Option 2.

2. Costs of Sealift Ships

To begin building a costing model for sealift ships, one must determine the relevant costs of the ships. The costs of concern are those that are directly affected by the purchase,

repair or operation of the ships. Determination of the major costs of sealift ships can be accomplished by using a life-cycle model. This model includes 7 major steps. The steps begin with the purchase or building of the ship for the purpose of sealift and continue until the ship is scrapped or sold. The following is a list of the seven major steps associated with the life-cycle of the Ready Reserve Force and the MPS [Ref. 13, 14]:

- Step 1: Ship Acquisition
- Step 2: Deactivation and Storage
- Step 3: Maintenance and Repair
- Step 4: Activation
- Step 5: Manning
- Step 6: Fulfillment of Operational Requirements (when necessary)
- Step 7: Re-Deactivation and Storage

The major costs associated with each step are discussed below for each of the alternatives.

a. Step 1: Ship Acquisition

(1) Option 1. Ships in the first alternative have already been purchased and therefore are a sunk cost. Past acquisition costs of the current fleet are not relevant in this analysis.

(2) Option 2. The cost of additional ships is a cost that must be paid in the future and therefore is a relevant cost. Ships for the RRF can be acquired from four basic sources: [Ref. 2:pg. 82]

1. NDRF - Ships in the NDRF may be selected for upgrade to the RRF. This is an indirect purchasing method because the ships were previously purchased by the U.S. for placement in the NDRF. Thus only costs associated with upgrading for sealift duty would be relevant.

2. Transfers - Commercial type (former USNS) ships transferred to the RRF by the Navy. The concept of opportunity costs would require a calculation of forgone opportunities resulting from the transfer.

3. Direct Purchase - Ships which are no longer commercially competitive, but which have a high military value may be purchased directly from U.S. and foreign owners. Direct purchasing began in 1984. In the past, older NDRF ships of little sealift value have been traded (or scrapped for cash) for more valuable ships that are placed into the RRF. The trade ratio in the past has been about two older ships for one RRF capable ship. [Ref. 13]

4. New Purchase - Ships may be purchased new for the purpose of sealift in the RRF. This is the least preferred method due to the high cost of new ships and the aspect of placing a ship in a reduced operating status while the ship is new and useful.

Ships in the Maritime Prepositioning Force were built or converted for the MPS program by three different shipbuilders. [Ref. 15:pg. 1] Essentially, the same acquisition options for the RRF hold true for the MPS ships. An additional cost

of acquisition of MPS ships is the loading of its war stock. This is because the war stock must be loaded prior to an MPS ship's deactivation.

b. Step 2: Deactivation and Storage

(1) Option 1. Ships that are in the RRF and prepositioned forces have been deactivated and stored in anticipation of a conflict. These costs are sunk costs to this option and are therefore not relevant.

(2) Option 2. Once it has been decided that a ship is to be placed into the RRF, it must be prepared for long term storage. If the ship has been in the NDRF it must be reactivated to bring the vessel up to a specified readiness status. NDRF conversion ship work includes an operational test of the main engines and major systems and dock trials. It also includes the installation of any special equipment such as radio or communication gear. [Ref. 13] Ships purchased directly or transferred from sources other than the NDRF must also go through a checking out process. Once the ship has been determined to be operationally sound, its deactivation (or lay-up) begins.

The lay-up of an RRF ship includes putting each of the ship's systems into a storage mode and placing the ship under dehumidification and cathodic protection. [Ref. 2:pg. 45] Cathodic protection is a method of electrically or chemically protecting the hull of a ship from the corrosive effects of salt water.

Dehumidification is the use of proper ventilation and the sealing of spaces to lower the amount of harmful moisture inside of the ship. The lay-up also includes ensuring that the propeller shaft is locked and that the anchors are free for running in case of an emergency.

Once the RRF ship is laid-up it is towed to its final storage area at one of the selected RRF ports along the East and West coasts of the United States. The ships are then anchored and nested with other RRF ships. [Ref. 1:pg. 27]

MPS ships are deactivated to a lesser degree than RRF ships. An indication of this is the fact that an RRF ship must be towed to its deactivation site while an MPS ship will steam to its site under its own power. One major difference is that the MPS ship has all of its combat stock on board prior to deactivation. Because of this, the MPS ship must periodically be activated to sail to a cargo maintenance facility.

c. Step 3: Maintenance and Repair

(1) Option 1. A ship that is being stored for possible no-notice use must be maintained in a state of readiness. The maintenance includes routine inspections and work on the dehumidification and cathodic protection systems, inspections and repair of machinery and engineering equipment, and periodic painting. [Ref. 2:pg. 57] RRF ships are periodically reactivated

with no notice to test the ability of the fleet to meet its five day, 10 day, and 20 day activation status.

The activations also contribute to RRF readiness to the extent that they identify and repair likely ship system failures. RRF testing activations therefore, are partially substitutable for the regular maintenance that occurs on the ships. [Ref. 16:pg. 15] Six to seven ships a year are activated in no-notice testing. [Ref. 13]

One significant cost of the maintenance of RRF ships is inspections by the American Bureau of Shipping (ABS). ABS establishes minimum material standards for safe operation of ships that each ship must meet. The standards include specifications of ship design such as hull thickness, insulation thickness on wires, and alarms. Certification by the ABS implies that a ship has met certain American standards of design and construction, but is not a guarantee that the ship can be activated. [Ref. 16:pg. 10]

MPS ships are maintained by civilian personnel under charter by the Military Sealift Command. Additionally, the military cargo equipment on board is maintained by a separate contractor. [Ref. 15:pg. 1] In this study the cost of maintenance of the military cargo on board MPS ships is not considered for two reasons. First, this study is aimed at providing a way to determine the effectiveness of the ship as a means of delivering cargo. Though the cost of maintaining and operating a ship will have an

effect upon the performance of the ship, the maintenance of its cargo will not. Second, any money spent on maintenance facilities for MPS ships is considered a sunk costs. If it is determined that new facilities are needed to support MPS ships, then that cost should be included in the analysis.

(2) Option 2. Since an additional ship purchased for sealift must be maintained, the same costs as those described above in Option 1 also pertain to Option 2.

d. Step 4: Activation

(1) Option 1. To "Activate an RRF ship means to repair it to operating condition and test it in sea trials". [Ref. 16:pg. A-1] Upon the activation of specific operational orders and plans the Military Sealift Command determines the need of RRF ships to fulfill the logistic requirements of the plans and orders. [Ref. 2:pg. 86] If there is a need for RRF ships, MSC informs the CNO Strategic Sealift Division (OP-42) of the requirement. The Assistant Secretary of the Navy for Shipbuilding and Logistics is then contacted by OP-42 for approval and funding of shipyard work and crewing of the required ships. The CNO will direct MSC to activate certain ships. MSC will then inform MARAD of the exact dates that the ships are needed. MARAD then directs the Ship Manager to begin the activation process. Once the ship is activated it is transferred to the operational control of MSC.

Although an RRF ship may be stored at one port, it may be taken to another port for reactivation work. This arrangement is necessary because of the constraints placed upon the storage port including a limitation of skilled workers and time for activation. The following steps take place upon initiation of activation of an RRF ship: [Ref. 17:pg. 5-2]

1. Breakout - This is the preparation of a designated ship for movement to activation facilities. It may be necessary to move entire nests of ships to retrieve the ship that has been designated. This is not required for ships that are to be activated at their storage port.

2. Tow - The towing of the designated ship from its storage port to the activation facility.

3. Activation - Ships are activated according to activation specifications. This includes bringing all specified systems and engineering equipment on board the ship to operational standards. Once activation work on a ship is considered completed, the ship must conduct dock trials for proof of readiness. Dock trials prepare the ship for sea trials and consists of testing the systems and equipment on-board a ship while tied to a pier.

4. Inspections - RRF ships must be inspected by the U.S. Coast Guard and the Federal Communication Commission (FCC) for certification of hull, major machinery, and designated systems.

5. Sea Trial - Once an RRF ship's propulsion plant can reliably hold steam, the underway testing of all of its shipboard machinery is conducted. Sea trials usually last 24 hours or longer and include the following: [Ref. 16:pg. A-3]

1. Steaming 16 hours at full power
2. Testing electronic communication and navigation equipment.
3. Checking rudder response
4. Conducting emergency maneuvers (full ahead to full astern and full astern to full ahead)
5. Testing cargo boom capacity
6. Delivery - Delivery is formally effected when MSC accepts operational control of the vessel. MSC takes control once it has been proved that the ship is ready for sea.

The higher readiness of the MPS dictates that many of the steps that occur for RRF ships are not required for MPS ships. Steps 1-6 above do not take place on an MPS ship. Once an MPS squadron is directed to activate, the crew on board the ships in the squadron will prepare the ships for steaming to the war port. The MPS ships set sail to the war port when the ship is considered ready by the on board crew.

(2) Alternative 2. The activation of additional ships in the RRF or MPS would essentially be similar to those already in the fleet as described in Alternative 1.

•. **Step 5: Manning**

(1) Alternative 1. Ships of the Ready Reserve will be manned by merchant seamen. Billets needed to operate a sealift ship are broken into six groups: licensed deck, engine, and radio and

unlicensed deck, engine, and radio. Funding for the manning of RRF ships must be approved by the Assistant Secretary of the Navy for Shipbuilding and Logistics. The process of manning RRF ships is done concurrently with their activation. Once the ship is manned it is ready for duty as assigned by MSC. [Ref. 2:pg. 60]

MPS ships are continually manned by a crew of approximately 40 persons. [Ref. 1:pg. 21] The cost of manning ships in the MPS is considered as part of the maintenance cost of the ships.

(2) Option 2. Fleet additions to the RRF and the prepositioning forces would essentially be the same as that described in Option 1.

f. Step 6: Fulfillment of Operational Requirements

(1) Option 1. The process of military mobility for the RRF involves transporting goods from the continental United States to anywhere in the world. This process can be broken down into a set of steps or transportation linkages. [Ref. 18:pg. 83] The linkages involved in the process start at the depot storage of needed war-fighting materials and end at the deployment of the materials for combat. The individual linkages are as follows:

START: DEPOT STORAGE

1. Stowage breakout and preparation for transportation
2. Loading of land transportation vehicles (truck or train)
3. Marshal land vehicles for land transit
4. Land transit
5. Unload land transit vehicles

6. Port material staging
7. Load Ships
8. Depart Port/Sea Transit
9. Enter War Theater Port
10. Unload Ships
11. Load forward theater transit vehicles
12. Land/Air transit
13. Unload land transit vehicles
14. Marshal equipment for combat deployment

FINISH: DEPLOYMENT TO COMBAT

From the above transportation links we can eliminate links that do not effect the cost of providing sealift. These are links that do not involve military sealift operations. The links that can be eliminated in the transportation leg from breakout to loading are items one through six. The linkages that can be eliminated after the materials reach the war zone are items eleven through fourteen.

As one can see, the linkages eliminated do not contain the use of sealift ships and should not be considered in the cost of sealift ships. In other words, the costs of the linkages eliminated would occur no matter what type of sealift ship is considered (assuming sealift is used in a conflict). The transportation links that remain (steps 7 through 10) contain the operational costs of providing or operating sealift ships and therefore should be considered further. Each of the steps involving sealift is discussed below.

(1) Operational linkage no. 7: Load Ships

Methods for loading the ships will vary by ship type. Roll-on/Roll-off (RO/RO) ships have the advantage of being able to drive the cargo into the holding cells. Other types of ships must have their cargos loaded by crane and placed into position by forklift or other means. Proper loading must take into consideration the stability of the ship as a floating platform and the ships maximum carrying capacity. Usually these are figured into the staging of the materials prior to loading.

(2) Operational Linkage no. 8: Depart Port/Sea Transit

Once a ship is loaded it sets sail for the war region. During wartime the ships will normally transit out to sea along known routes that have been swept of potential mines (Q-Routes). Once in the open ocean the ship may steam independently or within a convoy. If the ship is to sail in a convoy it will normally marshall with the other ships somewhere along its transit route.

(3) Operational linkage no. 9: Enter Port

After the sea transit, a sealift ship will normally transit another Q-Route prior to entering the arrival port. If facilities are not available or the piers at the arriving port are full, the ship may be anchored outside the port.

(4) Operational linkage no. 10: Unload Ships

Ships that have arrived in the war region ports will be unloaded upon arrival. Materials are taken off in the reverse order

as they were loaded. Since there is no concern about efficient use of space as in loading, this event takes considerably less time than linkage no. 7 (loading). Ships that are anchored outside the port may be unloaded by barge and/or helicopter.

The major difference in operating an MPS ship in comparison to the RRF is that the MPS ship does not need to be loaded after the beginning of a crises. As stated in Section B-1 above, loading costs are considered as part of the acquisition costs of an MPS ship. The other operating costs (depart port/sea transit, enter port, and unloading) are similar in nature to those of RRF ships.

(2) Option 2. The operational requirements of additional RRF and prepositioning ships would essentially be the same as those already in the fleet.

g. Step 7: Deactivation and Storage

(1) Option 1. Sealift ships that have been activated during a conflict must be preserved for the next conflict. Depending upon the condition of ship after activation, the process needed to deactivate a sealift ship after activation may be more or less demanding than the initial deactivation (step 2). If the ship has been used aggressively during the conflict it may need major engineering or systems repairs. On the other hand, if the ship was used only lightly, the task of deactivation and thus the cost of the second deactivation should be less than the first.

(2) Option 2. Deactivation and storage procedures for additional RRF and prepositioning ships would essentially be the same as for Option 1.

E. THE MODEL

The U.S. federal government has neither a price mechanism which points the way to greater efficiency, nor competitive forces which induce government units to carry out each function at minimum cost. [Ref. 19:pg. 107] The desire of profits and the threat of bankruptcy put pressure on private firms to seek out profitable innovations and efficient methods. In the federal government, by contrast, there is no profit incentive and rewards such as promotions and salary increases do not depend on profits. Also, in most federal government operations, an objective criterion of efficiency is not readily available. [Ref. 19:pg. 108] In the cases where a criterion is available the incentives to seek profitable innovations and efficient or least cost methods is not very strong. For these reasons, systematic quantitative analysis in military decisions is potentially much more important than in the private sector.

The derivation of the model begins with a discussion of optimal, efficient, and feasible solutions. Once these have been discussed an effectiveness index is developed so sealift fleets of differing ship types can be compared. Finally, a discussion of the

optimization process is presented along with an example of calculating the effectiveness indices of different ships.

1. Optimal, Efficient, and Feasible Solutions

In order to proceed with an economic analysis we must define efficient, optimal, and feasible solutions. Efficient solutions are those in which one output can not be increased without sacrificing (decreasing) another. [Ref. 19:pg. 109] In public economics, resource allocations that have the property that an output choice can make no one better off without someone else being made worse off are called Pareto-Efficient. [Ref. 20:pg. 63] Although any technically efficient solution implies no waste of resources, the value of the solution to decision makers may not be maximized (optimal).

Feasible solutions are those obtainable with a given set of inputs, but these may not all be technically efficient. Both efficient and feasible solutions can be displayed using a production possibilities curve. A production possibilities curve traces the various amounts of two goods or outputs that can be produced efficiently with a given technology and resources. [Ref. 20: pg. 10] Feasible solutions are bounded by the production possibilities curve.

Two outputs (or characteristics) of sealift that can be displayed on a production possibilities curve are capacity and speed. For a set amount of resources (at a fixed technology level),

sealift can provide different amounts of carrying capacity in exchange for speed. When limited funding resources are directed at providing more carrying capacity, then speed of delivery will be sacrificed. If those resources are directed at providing more speed then some carrying capacity is sacrificed.

The trade-off between speed and capacity is a continuing debate among sealift policy makers. Fleet size is one of the principal determinants of cargo lift capability and is limited either by the amount of money available to spend on sealift ships or by existing capacity. Ship speed is also a principal determinant and is limited to the technologies that government can afford. But as speed increases, more of a given investment must be used to buy increased horsepower, and correspondingly more demanding engineering and production methodologies. Each dollar spent on more horsepower and more demanding engineering and production methodologies is a dollar not available on additional hulls. In other words, fleet size, (i.e. capacity), becomes smaller as speed increases. [Ref. 18:pg. 89]

In this paper the speed of a ship also takes into consideration the speed of loading, unloading and the preparation time for deploying the ship. Obviously, if more funding is expended on maintaining a ship so that the ship can be deployed sooner, fewer ships can be kept in the fleet for a fixed funding level. Also, if improved loading and unloading features such as more

cranes or built-in loading ramps are added, then fewer ships with those features may be purchased.

Different ship types can therefore be described in terms of two characteristics; speed and capacity. Illustrating alternative ships in terms of speed and capacity, a "production possibilities curve" can be plotted. As shown in Figure 3, different ships can be thought of as "producing" different combinations of speed and capacity.

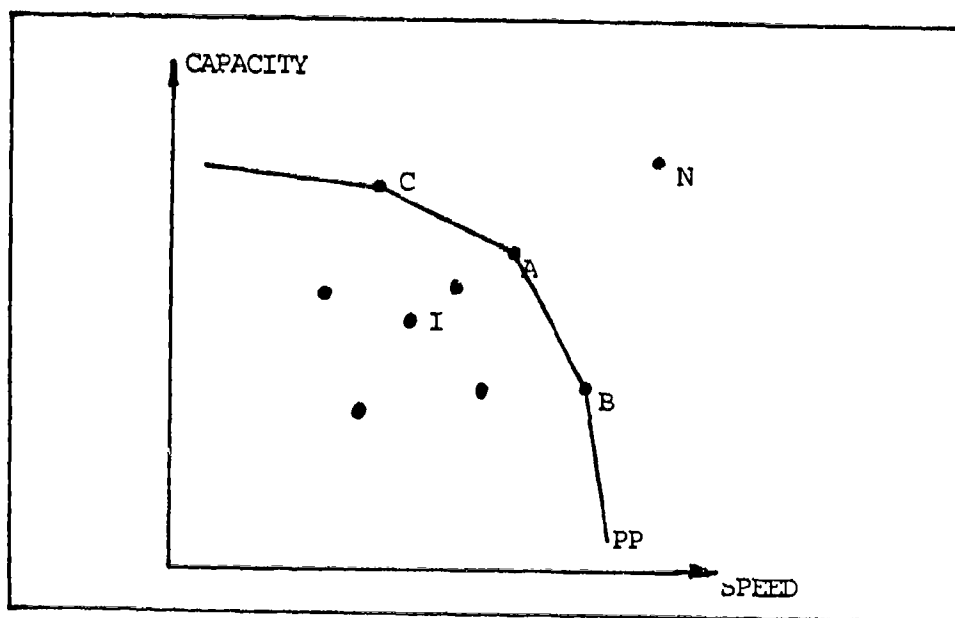


Figure 3. Production Possibilities Curve

Figure 3 shows the relationship between speed and capacity that can be purchased given a fixed amount of funding. Point C in

Figure 3 indicates that with the use of a fleet of slow ships, larger amounts of capacity may be purchased. Conversely, point B suggests that by using faster ships, fewer may be purchased and thus the total capacity is smaller. Any choice of speed and capacity along the curve PP represents a technically efficient use of the given resources and technology.

Fleet type A lies along the production possibilities curve and therefore is an efficient choice. Fleet type B also lies along the production possibilities curve, but is faster. For example, ships in fleet type B may have larger and less fuel efficient propulsion plants or better cranes to load and unload more quickly. Because more funds were spent on the propulsion plant or better cranes, less funds could be spent on total hulls. Therefore the total capacity of fleet type B is less than fleet type A.

Fleet type C is also on the production possibilities curve, but is slower than fleet type A. For example, type C may have ships with larger hulls or larger numbers of hulls, but more economical propulsion plants or fewer loading devices than type A. Because less money was spent on the propulsion plant or loading devices, more money could be used to buy larger hulls or larger numbers of hulls.

Choices inside of the curve are feasible choices, but are not efficient. For instance, ships inside the production possibilities curve may rely on older technologies. An example of

a fleet inside PP may be steam powered ships purchased new (fleet I). Steam ships are much more complex and demanding than diesel powered ships and therefore would cost more in comparison for the same capability. Alternatively, the capability (speed or capacity) that could be purchased for a fixed amount of money is less than for a more modern and more efficient ship. Choices outside the curve are not currently feasible, although both more speed and more capacity are always preferred to less of each.

Though technically efficient, most choices along the curve may not be preferred or optimal. For instance, very large capacities are worthless if goods cannot be delivered to the war zone in reasonable time. Similarly, very fast ships are of no use if their capacities are not sufficient to meet military logistical requirements. In order to determine the outputs that produce the most value to policy makers, we must develop criteria which can lead to an optimal choice along the production possibilities curve.

An optimal solution is one which, given a set of resources, produces an output with a maximum value in the face of known constraints. [Ref. 19:pg. 109] If the solution is not optimal, then one unit of a characteristic can be traded for another and the total value of the output increases. The key to optimality is to discover the value function of the decision maker(s).

The preferences of decision makers are required to determine the optimal solution. A decision maker can be asked to

evaluate the amount of one characteristic (speed) that he/she would be willing to sacrifice for an additional unit (tons of capacity) of another characteristic and remain equally satisfied. The result of such a pair-wise comparison of characteristics is the set of utility weights: U_{speed} and U_{capacity} (see Appendix A).

In this paper the pair-wise preferences of decision makers is assumed linear between attribute levels (higher and lower levels of speed and capacity). It is difficult enough to elicit pair-wise preferences from decision makers without the additional (but more realistic) assumption that these pair-wise preference relations might change when evaluated at different attribute levels. The linearity assumption is a local approximation of the "true" (convex) relationship of a policy maker's pair-wise preferences. The closer the alternatives are in terms of their characteristics, the better this approximation will be. [Ref. 21: footnote 5]

Let U_{speed} be the weight or utility value that the decision maker gives to the speed of a fleet of ships and U_{capacity} be the weight or utility value that the decision maker gives to the capacity of a fleet of ships. The ratio $U_{\text{speed}}/U_{\text{capacity}}$ can then be interpreted as the (constant) marginal rate of substitution (or trade off) between speed and capacity. [Ref. 21:pg. 8] Specifically, the ratio $U_{\text{speed}}/U_{\text{capacity}}$ represents how much speed a decision maker is willing to sacrifice for an additional amount of capacity. For instance, a ratio of 2/1 means that the decision

maker is willing to give up two units of capacity to obtain one unit of speed. The decision maker may have an even stronger preference (say 4/1) for speed over capacity because of an urgent need to get an initial amount of materials to the war zone to counter the spread of an aggressor.

The essential implication is that this ratio defines a decision maker's indifference curve. An indifference curve reveals those combinations of characteristics which an individual finds equally satisfactory. [Ref. 20:pg. 102] In other words, the indifference curve illustrates various combinations of capacity and speed which provide equal utility to the decision maker. A hypothetical set of indifference curves is shown in Figure 4.

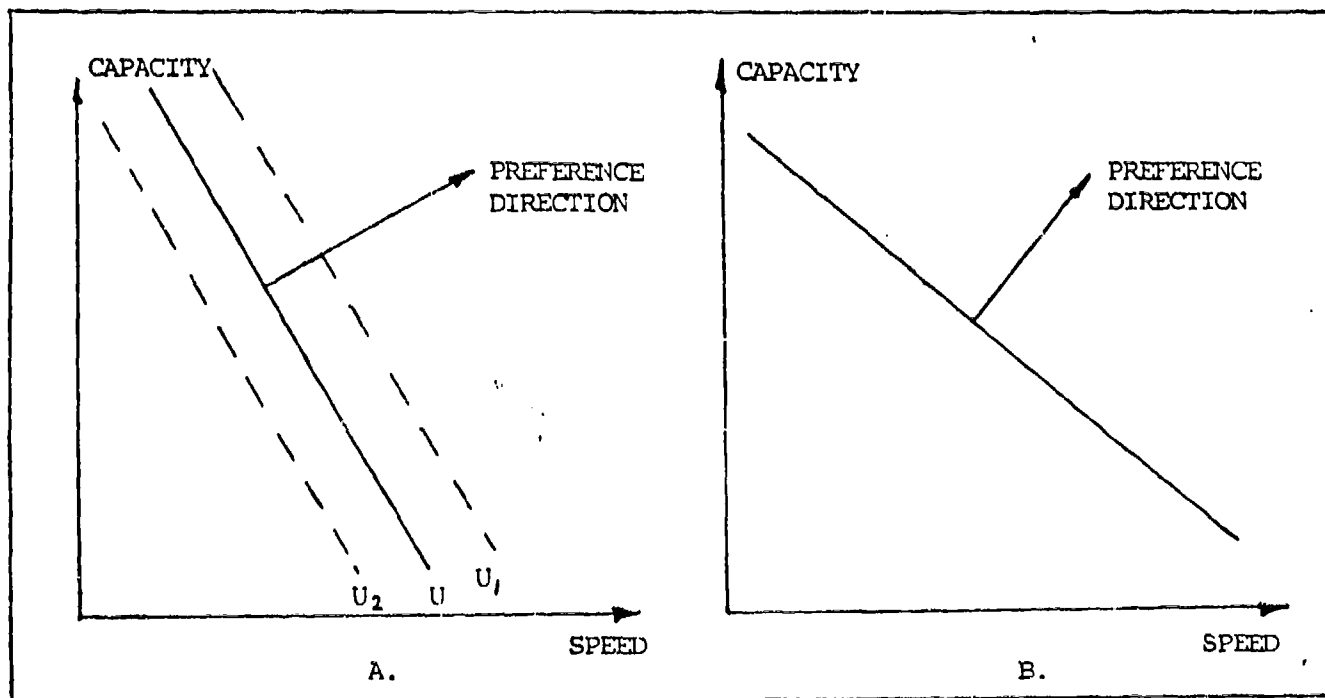


Figure 4. Sealift Indifference Curves

The curve U in Figure 4a displays various combinations of speed and capacity which the decision maker finds equally satisfying, (the utility remains the same). Decision makers would prefer curves outside of U , such as U_1 , to the curve U . More of both characteristics is preferred to less. Alternatively, decision makers would prefer the curve U to those curves inside of U such as

U_2 . The decision makers willingness to trade off speed for capacity is revealed in the slope of the indifference curve.

Figure 4b displays an indifference curve in which the decision maker prefers relatively more capacity and less speed than a decision maker whose preferences are reflected in Figure 4a. In this case the ratio of the utilities $U_{\text{speed}}/U_{\text{capacity}}$ (or the marginal rate of substitution) would be lower. In other words, in Fig. 4b the decision maker is willing to sacrifice less capacity for additional speed (say 2/1) than the decision maker in Fig. 4a (say 4/1). Note that the slope of a typical indifference curve in 4a may change to that in 4b when "enough" speed is finally achieved, since additional speed at the expense of a capacity is no longer as desirable. A decision maker's indifference curves and the production possibilities curve can now be integrated to determine the optimal combination of output characteristics desired.

2. Effectiveness Index

Determining the production possibility curve for sealift ships with varying characteristics of speed and capacity is relatively straight-forward given the ships available and market prices. A more difficult task is determining the relevant utility weights for speed and capacity.

Let, U_{capacity} be the weight that policy makers give to the characteristic capacity and let U_{speed} be the weight policy makers give to the characteristic speed (see Appendix A for one possible

derivation of such weights). A policy maker's sealift utility function will then be the sum of capacity and speed multiplied by their respective weights or: $U = U_{\text{capacity}} * C + U_{\text{speed}} * S$. The equation can be rewritten as:

$$C = U/U_{\text{capacity}} - (U_{\text{speed}}/U_{\text{capacity}}) * S$$

where $U_{\text{speed}}/U_{\text{capacity}}$ is equal to the slope of the utility (or indifference) curve. Note that the term $U_{\text{speed}}/U_{\text{capacity}}$ is equal to the marginal rate of substitution that a policy maker gives to capacity and speed. The term $U_{\text{speed}}/U_{\text{capacity}}$ is therefore the slope of the indifference curve of capacity and speed. The problem now becomes one of determining the relative weights U_{capacity} and U_{speed} (see Appendix A).

The weights, U_{capacity} and U_{speed} , can be used to determine the Effectiveness Index for various fleets (or ship types). The index is the sum of the weights multiplied by the respective ship (normalized) characteristics, speed and capacity.

$$EI = U_{\text{capacity}} * (\text{Capacity}) + U_{\text{speed}} * (\text{Speed})$$

Again, speed is a measure of the quickness of the ship to meet its objectives and therefore is measured by the time that it takes to perform its mission. To follow the "bigger is better" maxim, it is necessary to subtract the actual time it takes a ship to perform its mission from the maximum allowed to perform the

mission (sealift delivery requirement). Ships that have actual times that are greater than the requirement are not considered. Therefore:

$$EI = U_{\text{capacity}} * (\text{Capacity}) + U_{\text{speed}} * (\text{Time}_{\text{Requirement}} - \text{Time}_{\text{Actual}})$$

The ratio of $U_{\text{speed}}/U_{\text{capacity}}$ is the marginal rate of substitution and therefore is the slope of the indifference curve of capacity and speed. The slope of the indifference (or utility) curve then determines the type of fleet(s) that is (are) most preferred by decision makers. Figure 5a displays the optimal decision given sealift fleets described by the production possibilities curve in Figure 3, combined with the utility function of decision makers. In Figure 5a, the most preferred type of fleet consists of ships in fleet type A.

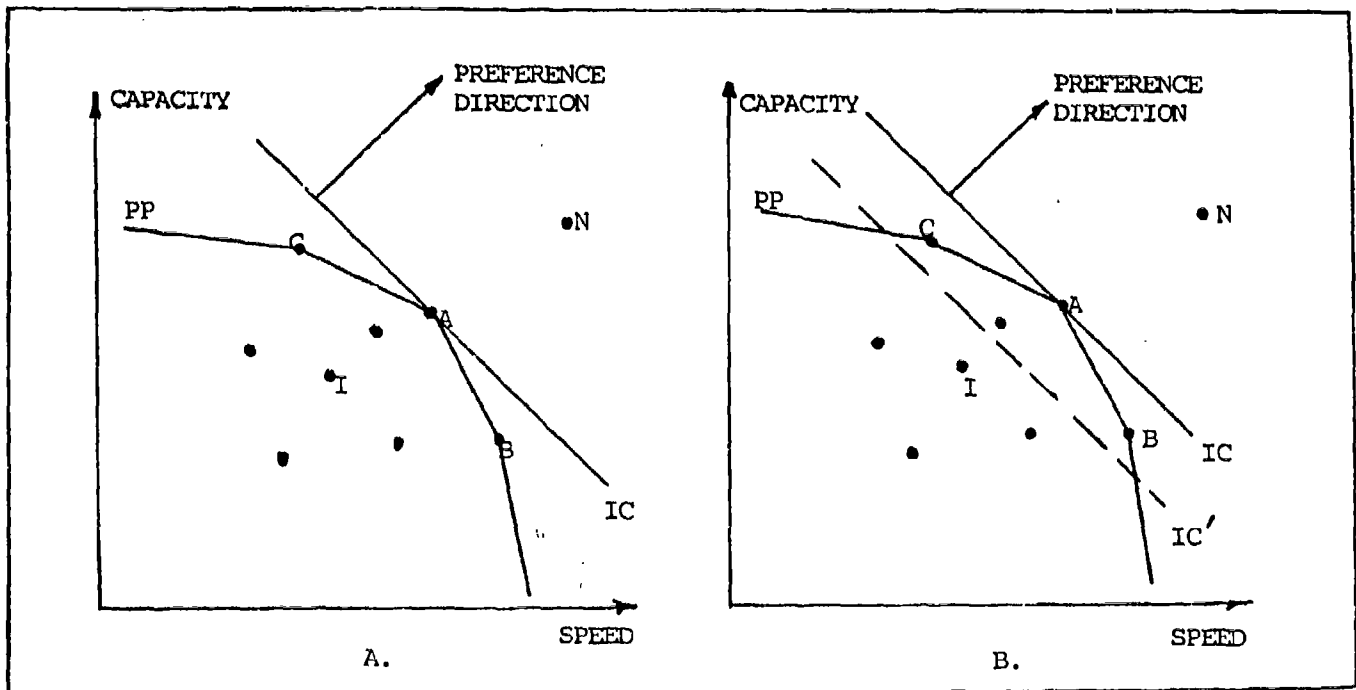


Figure 5. Optimal Sealift Choices

The problem is that there may not be enough ships (i.e. total capacity) in fleet type A to meet the requirements of sealift designated by policy makers. Under the condition that no new ships of type A can be acquired, the decision maker would choose along a less preferred indifference curve such as IC' in Figure 5b. Lower and lower indifference curves would be pursued until the required capacity of sealift for the amount of money available is satisfied. Note, that by moving the indifference curve inward, feasible and

efficient ships are chosen, but not optimal ones, to fulfill the sealift mission.

3. Optimization Process

The level of effectiveness can now be used to determine the optimal fleet of sealift ships given existing ship types. The derivation of the optimal fleet is accomplished by continuing to use the fleet (or group of ships with the same characteristics) of one ship type as long as the ratio of the Effectiveness Index of that fleet to the a second fleet (with a different characteristic combination) is greater than the ratio of the costs of the fleets or:

$$(EI \text{ fleet1}) / (EI \text{ fleet2}) > (\text{Cost fleet1} / \text{Cost fleet2})$$

By manipulating the above ratios we can choose the ship with the higher ratios of Effectiveness to cost. For instance, in comparing two fleets we would choose fleet 1, made of ships of type 1, if the following is true:

$$(EI \text{ fleet1}) / (\text{Cost fleet1}) > (EI \text{ fleet2}) / (\text{Cost fleet2})$$

In this paper the term Quality Ratio will be used to describe the ratio of the Effectiveness Index of a fleet of a certain type of ships to the total cost of the fleet. Therefore, the quality ratio of the nth fleet of ships (with a peculiar

combination of speed and capacity) in the total sealift fleet is described as:

$$QR_n = EIn/C_n$$

where C_n represents the total relevant cost of the n th fleet.

Ships of different types have characteristics that make them more or less effective for a given cost or more or less costly for a given effectiveness. For instance, steamships that have been deactivated for periods of time tend to be more expensive to activate than diesel-driven ships. [Ref. 16:pg. 13] This is due to several factors. First, the diesel ship is less complex and thus takes less personnel and time to bring the ship to full activation. Also, because of the steamship's complexity, it is more expensive to test and thus is usually tested less often than diesel ships. More problems, therefore, tend to arise during the activation of steamships compounding its cost to deploy. [Ref. 16:pg. G-1] Diesel ships would tend to have higher quality ratios than steamships and would therefore be preferred.

Other characteristics such as the amount of maintenance that a ship receives during layup and the age of a ship tend to affect the cost of activation. [Ref. 16:pg. 13] Here, the more maintenance a ship receives during layup the lower the costs of activation.

As mentioned above, some ship classes take more time to perform loading and unloading tasks than others. Newer ships, such as RO/ROs, allow loading by driving vehicles or equipment onto the ships and thus are loaded quicker (i.e. time reduced from some standard is greater) than other types. The decreased loading time would thus tend to raise the effectiveness ratio for RO/RO fleets relative to fleets with similar ships and conventional loading. Examples describing the derivation of the quality ratio for two fleets consisting of different types of ships are given in the next two sections. The first example demonstrates the determination of the Quality Ratio for the existing fleet (Option 1). The second example demonstrates the determination of the Quality Ratio for additions to the existing fleet (Option 2).

F. COST AND TIME MODELS

In the sections below, models will be developed for the RRF and the MPS. The cost model of the respective fleet types is first determined. The delivery times of the respective fleets is then determined. The cost and time models can then be used to compute the Effectiveness Indices for the respective fleets.

The sealift costs used to develop the following cost models are the relevant costs examined in Section D. The models depend upon policy makers accounting for the costs in the separate accounts given in that section (ie, acquisition, deactivation and storage, etc.). Once the costs outlined in Section D can be determined, the

policy maker can use the Quality Ratios to determine the most effective fleet of ships to activate in a time of crisis given a fixed budget. Therefore, by accounting for the costs of sealift ships in a manner which allows the calculation of Quality Ratios, significant future savings may be the result.

1. Option 1

a. RRF

The first step in developing an optimal mix for the RRF is determining a measure of effectiveness for the ships. Not all ships can or should be compared. For instance, ships that carry liquid cargos such as fuel or lubricants should not be compared with ships that carry ammunition. This is because the measurement of a certain amount of fuel carried on a tanker (tons) has little correspondence to the ship carrying ammunition (ft^3). Therefore ships carrying fundamentally different products should be compared separately.

In this model, the effectiveness of cargo (dry) ships is measured as the amount of area of cargo delivered in a period of time: ft^2/Day . The Effectiveness Index should use ft^3 as the units of capacity. As mentioned above, area is preferred to weight since it takes into consideration the ability to load awkward or bulky cargo such as artillery. The effectiveness measurement of tankers shall be the weight of liquid cargo delivered in a period of time

or: Tons/Day. Therefore, the Effectiveness Index of tankers should use the Capacity designated in tons.

(1) *Costs*: In the case of the RRF the relevant costs are the maintenance costs and the contingent costs. The costs of acquisition have been paid and therefore are considered sunk costs. Each of the costs associated with the RRF is modeled below:

1. *Maintenance costs*: The maintenance costs of the RRF are the stream of future costs for maintaining each ship. The cost of maintenance for each year must be multiplied by a discount factor to standardize the payments to the current year. A discount rate is an interest rate used to convert future payments into present values. [Ref. 22:pg. 736] The costs of maintenance for a ship (ship number 1) can be represented by the term Cl_{maint} . This term represents the sum of the stream of future payments for each year that the ship is held in the RRF or:

$$Cl_{maint} = \text{Sum}[Cl_{yr1}(f_1) + Cl_{yr2}(f_2) + \dots + Cl_{yrM}(f_m)]$$

The term f_m is the discount rate factor for the m^{th} year in the future that the RRF ship is maintained. Similarly, the cost of maintenance for some second ship in the RRF may be represented by $C2_{maint}$ while the cost of the n^{th} ship is Cn_{maint} .

2. *Activation Costs*: The cost to activate a ship (ship number one) is represented by the term Cl_{act} . The cost to activate the n^{th} ship can then be represented by the term Cn_{act} .

3. Operational Costs: The operating costs of an RRF ship is the cost of the ship to make a round trip to the war zone and back. This cost is the sum of the ship's steaming costs and its loading costs. Loading costs are a function of the time it takes to load the ship. Roll-on/roll-off ships take considerably less time to load than break-bulk ships and therefore should be less costly to load. Steaming costs are a function of the distance that the ship must sail and the efficiency of the ship's engineering plant. Like the maintenance and activation costs, the cost of steaming the first ship is represented by $C1_{op}$ while the cost of the nth ship is represented by Cn_{op} .

4. Manning Costs: The costs to man an RRF ship (ship number 1) in the time of crises is represented by $C1_{man}$ while the cost to man the nth ship is Cn_{man} .

5. Re-Deactivation Costs: Once the ship has finished its duty during the time of crises it must be deactivated. This deactivation would be subsequent to the initial activation that places the ship in the RRF. Like the other costs associated with the RRF, the cost of re-deactivating the first ship is represented by $C1_{reduct}$ while the cost to re-deactivate the nth ship is represented by Cn_{reduct} .

The total cost of the first ship can now be represented by $C1_{tot}$. This cost is the sum of the five costs discussed above or:

$$C1_{tot} = C1_{maint} + C1_{act} + C1_{op} + C1_{man} + C1_{reduct}. \quad (1)$$

(2) Time: The factor used in the denominator of the performance ratio (PR) is time. The time used is that for which it takes a ship in the RRF to deliver a shipload of materials from the beginning of activation. The total time is therefore the time needed to activate, man, load, transit to the war port, and unload. The total time for the first ship is denoted as T_1 where:

$$T_{1_{tot}} = T_{1_{act}} + T_{1_{man}} + T_{1_{load}} + T_{1_{stm}} + T_{1_{unload}} \quad (2)$$

The total time for the n th ship is denoted as T_n . Note that the total time does not take into consideration the time needed to steam from the war port back to the United States. Also, if manning or loading take place concurrently with activation, then the times would not be added outright. The time used would be the time from the beginning of activation to the beginning of steaming.

The time of the return leg should not be considered in the case of the initial load because the performance of the ship is only based upon how fast the ship can get its load to the war. If the ships are to be used in repeat trips to the war zone, subsequent trips must include the return times of the ships.

The optimal ships may now be selected from the ratio of PR to COST. The ships with the higher quality ratios should be selected over those with lesser ratios. Therefore ships with low quality ratios may be eliminated as long as the cumulative

capacity does not become less than total cargo requirement of the scenario.

b. MPS

The model for prepositioned ships may be determined along the same lines as the model for the RRF. Again, the measurement of effectiveness is determined first. Here we need to reflect upon the characteristics of the prepositioned ships. MPS ships carry a variety of cargo ranging from tanks and ammunition to water, petroleum and fuel. The measurement of effectiveness must be able to take into consideration the variety of cargo. The measure of effectiveness that is used for MPS ships is then the weight of cargo delivered in a period of time: Tons/Day. Therefore, the units of capacity used in the Effectiveness Index should be tons. By the nature of prepositioning, the time needed to reach the war zone is reduced. Each of the costs associated with prepositioning is modeled in the same manner as RRF ships.

(1) Costs:

1. Maintenance costs: The cost of manning is included in the maintenance of the ships. Therefore, the cost of maintenance is higher than it would normally be if the ships were not continually manned. The maintenance costs of a prepositioned ship may also include costs not associated with other forms of sealift such as the costs to rent an anchorage site. As in the model for the RRF, the maintenance costs are a stream of future costs for maintaining

each ship. The term representing the maintenance cost of the nth ship is again represented as:

$$Cn_{\text{maint}} = \text{Sum}[Cn_{\text{yr1}}(f_1) + Cn_{\text{yr2}}(f_2) + \dots + Cn_{\text{yrM}}(f_M)]$$

Again, the term f_m is the discount rate factor for the m^{th} year in the future that the prepositioned ship is maintained.

2. Activation Costs: As in the case of the RRF, the term Cn_{act} is used to represent the cost to activate the nth ship in the prepositioned fleet.

3. Operating Costs: Because the ships in the prepositioned force are loaded prior to a crises, their loading costs are therefore sunk costs. The primary operational cost associated with the prepositioned force is the steaming cost. Steaming costs should include the cost of the prepositioned ship to make a round trip. Prepositioned ships may be used in repetitive trips in a time of crises. Therefore in such situations the steaming costs must also include the costs to sail from the war zone to the United States after the initial unloading. As in the model of the RRF, the cost to operate the nth ship in the prepositioned force will be represented as Cn_{op} .

4. Re-Deactivation Costs: The re-deactivation of the prepositioned ships is more involved than that of the RRF because it includes the cost of loading the ship with war stock. The cost of loading would include the cost of steaming to the prepositioned

anchorage after loading. Again the re-deactivation costs for the nth ship are modeled as Cn_{redact} .

The total cost of the of the nth ship to perform its mission is represented by:

$$Cn_{\text{tot}} = Cn_{\text{maint}} + Cn_{\text{act}} + Cn_{\text{op}} + Cn_{\text{redact}} \quad (3)$$

(2) Time: The time used in the Effectiveness Index is the time a prepositioned ship takes to deliver its materials. The total time is therefore the time to activate, transit to the war port, and unload. The total time for the nth ship is denoted as Tn_{tot} where:

$$Tn_{\text{tot}} = Tn_{\text{act}} + Tn_{\text{stm}} + Tn_{\text{unload}} \quad (4)$$

If the ship is to make only one trip, the time of the return trip should not be considered. This is because the return time is not considered as a measure of the effectiveness of the ship. If the ship is directed to make numerous trips after its first unloading, than the time that the ship takes to reach a port to be reloaded should be part of the analysis.

Like the case of the RRF model, the optimal mix of MPS ships is the one with the highest quality ratios. Ships with the lowest quality ratios may be eliminated unless the cumulative cargo capacity is reduced below the scenario capacity requirements.

2. Option 2

As in Option 1, the measure of effectiveness should coincide with the type of ship and fleet for which the ship is being acquired. For instance, if the ship is a cargo ship (dry) to be used in the RRF than the measure of effectiveness should be ft^2/Day (the same as for Option 1). Units of ft^2 should be used in the Effectiveness Index. Similarly, ships acquired for use in the MPS should use tons per day as the measurement of effectiveness. The unit of Tons are therefore the units of MPS capacity.

For the option of acquiring new ships for the RRF and prepositioned forces the full life-cycle costs must be considered. Acquisition costs along with deactivation and storage costs are no longer sunk costs as they were in Alternative 1. Each of the costs associated with addition of a ship to the sealift fleet is modeled below.

a. Costs

1. Acquisition cost: Acquisition costs are the total costs spent to place a new ship into either the RRF or the MPS. If payment for the ships is to take place over a period of time than the value of the payment is the net present value for the year of placement into the fleet. The terms for the n th ship is modeled as Cn_{purch} , where Cn_{purch} is the total payment for a lump-sum payment ship and is equal to the net present value for ships when there are payments over time.

2. Deactivation and Storage cost: Any ship acquired for the purpose of sealift will be deactivated and placed into storage. The level of deactivation will depend upon the fleet in which the ship is placed. As discussed earlier, prepositioned ships are kept at a higher readiness level than RRF ships and therefore will have smaller deactivation and storage costs. The deactivation and storage costs for the n th ship are modeled by the term Cn_{dst} . It should be noted that the cost of acquiring an MPS ship would also include the loading cost for its load of materials.

3. As in Option 1, the maintenance costs of additional ships will be the stream of future costs for the maintenance. Again, the maintenance costs for the n th ship can be represented as Cn_{maint} . As noted for Option 1, the cost of maintaining prepositioned ships also includes the manning costs.

4. Activation Costs: The costs to activate an additional ship is essentially includes the same costs as for Option 1 and is represented by the term Cn_{act} .

5. Operational Costs: As for Option 1, the costs for the operation of an additional (n th) sealift ship are represented by the term Cn_{op} .

6. Manning Costs: Marginal manning costs only occur in a time of crises for the RRF. As in Alternative 1, manning costs for prepositioned forces are included in the cost of maintaining those

ships. The cost of manning in the case of a ship added to the RRF is modeled by the term Cn_{man} .

7. Re-Deactivation Costs: Re-Deactivation costs for ships added to the RRF or MPS squadrons are modeled by the term Cn_{redact} .

The total cost for the addition of a ship to the RRF or the MPS would be the sum of each of the marginal costs of the ship. For the n th ship that cost would be:

$$\text{RRF: } Cn_{tot} = Cn_{pur} + Cn_{dst} + Cn_{maint} + Cn_{act} + Cn_{man} + Cn_{op} + Cn_{redac} \quad (5)$$

$$\text{MPS: } Cn_{tot} = Cn_{pur} + Cn_{dst} + Cn_{maint} + Cn_{act} + Cn_{op} + Cn_{redac} \quad (6)$$

b. Time

The factor, time, is the same used in the Effectiveness Index for Option 1. The time measurements for additions to the RRF and MPS squadrons would be:

$$\text{RRF: } Tn_{tot} = Tn_{act} + Tn_{man} + Tn_{load} + Tn_{stm} + Tn_{unload} \quad (7)$$

$$\text{MPS: } Tn_{tot} = Tn_{act} + Tn_{stm} + Tn_{unload} \quad (8)$$

Each element of time is the same as described in Option 1.

G. OPTIMIZATION PROCEDURES

Once the measure of effectiveness, the Effectiveness Index, and the cost of a ship in a certain fleet has been determined, then the fleet may be optimized. The optimization procedures will be presented for both Options 1 and 2.

1. Option 1

a. RRF

The total cost and the Effectiveness Index of each RRF ship may now be used to determine the optimal mix of existing ships to activate. For N ships in the RRF a table of the costs and performance can be produced as shown in Figure 6. In Figure 6, cumCAP is the cumulative capacity of the ships as each ship is added to the analysis. Both Capacity and the cumulative capacity are shown in ft² for the measurement of cargo capacity and cumulative cargo capacity respectively. The unit cumCost is the cumulative cost of all ships selected to be in the fleet. The analysis table for tankers would be the same except that the measurement of capacity and cumulative capacity would be given in tons.

SHIP	COST (\$)	cumCOST (\$)	CAPACITY (ft ²)	cumCAP (ft ²)	SPD (kts)	TIME (days)	EI	QR (EI/Cn)
-----	-----	-----	-----	-----	-----	-----	---	-----
S1	C1 _{tot}	C1 _{tot}	CAP1	CAP1	SP1	T1	EI1	QR1
S2	C2 _{tot}	C1 _{tot} + C2 _{tot}	CAP2	CAP1+ CAP2	SP2	T2	EI2	QR2
.
.
.
Sn	Cn _{tot}	SUM[C1- Cn]	CAPn	SUM [CAP1- CAPn]	SPn	Tn	EIn	QRn

Figure 6. Analysis Table.

Ships with higher quality ratios should be selected over ships with lower quality ratios. Therefore, select ships for the RRF by choosing the ship with the highest quality ratio first until these are used up and then selecting ships with decreasing quality ratios. The last ship selected would be the additional ship that provides a total cumulative capacity that just meets that required by the sealift scenario or whose cost added to the cumulative costs just exhausts the budget.

b. MPS

Prepositioned fleet ships may be least-cost optimized using the same procedures as for the RRF ships. As discussed above, the effectiveness of prepositioned ships should be measured in tons. In this case, the capacity measurement in Figure 6 would be measured in tons instead of ft².

c. RRF vs. MPS

In Sections 1a and 1b, the optimal selection of ships within a fleet (RRF or MPS) was determined. The two fleets may be optimized together. In this case, the costs and time factors that are relevant to the ships within the respective fleets should be used. For instance, equations (1) and (2) should be used for ships within the RRF fleet while equations (3) and (4) should be used for ships within the MPS squadrons. The units of cargo capacity must allow comparison between the fleets. Since MPS ships must use tons to measure their liquid carrying capacity, tons should be used as

the units of cargo capacity when comparing effectiveness between fleets.

The requirement (scenario) for getting a certain amount of materials to the war zone in a certain period of time is the same for both fleets. Again, ships with the highest quality ratios would be selected first until those are used up, and then select ships with decreasing quality ratios. The last ship selected would be the additional ship that provides a total cumulative capacity that just meets that required by the sealift requirement or whose cost added to the cumulative costs just exhausts the budget.

2. Option 2

Option 2 involves choosing ships to acquire for the RRF or the prepositioned forces. It is straight-forward when a ship must be added to one or the other fleets. A more complicated decision occurs when a ship can be placed in either of the fleets.

In this case, the Effectiveness Index of the ship must be estimated for both fleets. For instance, to calculate the performance ratio of the ship for the RRF the ship's carrying capacity should be used along with equations (5) and (7). In determining the performance ratio for the ship in the prepositioned force, the ship's carrying capacity would be used again, but now with equations (6) and (8). A comparison of the performance ratio for each fleet can now be made. Additional ships should be acquired and placed into the fleet which give the largest performance ratio.

H. EXAMPLE 1. (OPTIMIZATION OF CURRENT FLEET)

In this section an example of how to determine the Quality Ratios of different fleets (type of ships) is presented. The example uses two hypothetical ships with differing characteristics.

Note that ship speed is only part of the total measure of performance or quickness of the ship types. The measure of performance of speed is the amount of time less than the maximum allowable time set by policy makers (50 days in this example). Other factors include the activation, loading, unloading times.

	<u>Fast Ship Fleet</u>	<u>Slow Ship Fleet</u>
Ship Speed:	25 kts	18 kts
Time to Perform Mission:	30 days	40 days
Speed:	20 days	10 days
(measure of performance)		
Cargo Capacity:	12,000 ft ²	15,000 ft ²
Fleet Size:	5 ships	8 ships
Total Capacity:	60,000 ft ²	120,000 ft ²
<u>Relevant Costs</u>		
1.Acquisition and Storage:	\$98 Million/ship	\$50 Million/ship
2.Activation, Maintenance, Operating, Manning & Deactivation:	\$35 Million/ship	\$30 Million/ship
MINIMUM STANDARD REQUIREMENT:	50 days	
Option 1 Budget:	\$250 Million	
Option 2 Budget:	\$400 Million	

The budget for the existing ships is the cost of each ship for an expected contingency. This budget would include,

maintenance, activation, manning, operating, and deactivation costs. The new ship budget would include acquisition, storage, maintenance, activation, manning, operating, and deactivation costs.

1. Determination of Production Possibilities Curve

The production possibilities curve of the two fleets of ships can be shown graphically in Figure 7.

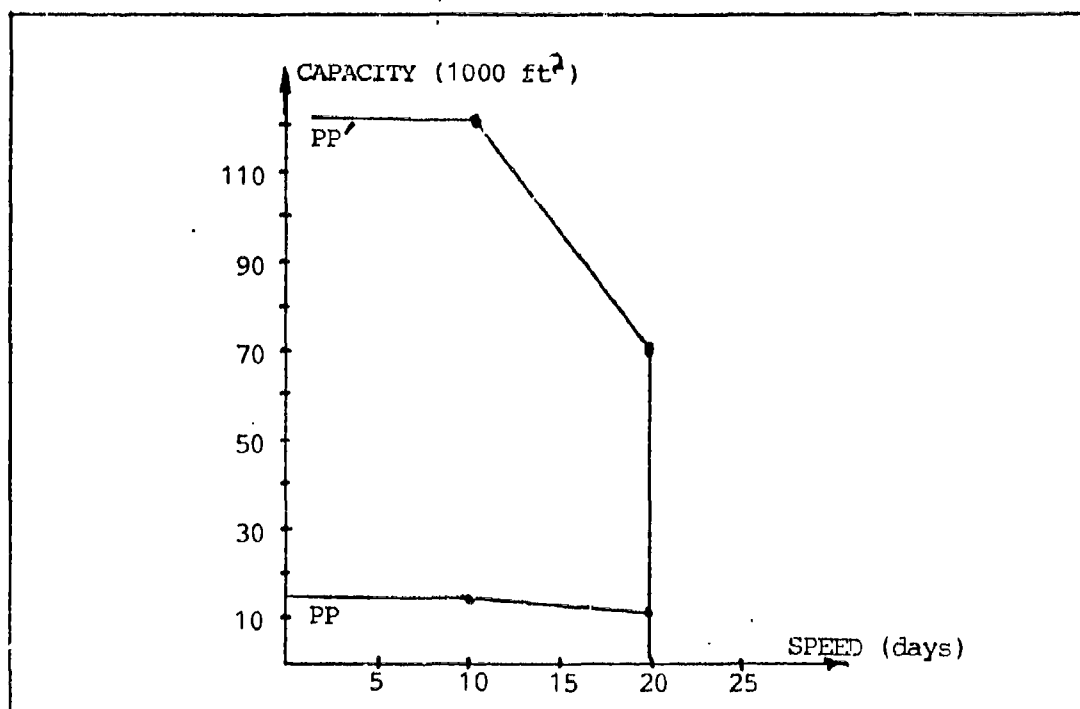


Figure 7. Existing Fleet Production Possibilities

PP is the production possibilities for a single ship in the existing fleet while PP' is the production possibilities of the entire existing fleet.

2. Determination of Indifference Curves

After surveying decision makers suppose it is found that the decision maker places the same value of an additional 10,000 ft² of war materials reaching the war zone as equal to the value of the materials reaching the war zone two days sooner. In other words 10,000 ft² = two days sooner delivery or one day is valued 5000 times more than 1 ft². Said another way, the policy maker would be willing to give up 1/5000 of a day for an additional ft² of capacity. The utility weights U_{capacity} and U_{speed} may be determined as they are in Appendix A. A table similar to Table A1 may be set up to display these calculations.

	CAPACITY	SPEED	Weights
CAPACITY (ft ²)	1	1/5000	$U_{\text{capacity}} = .0002/1.0002$
		=.0002	= .00019996
SPEED (days)	5000	1	$U_{\text{speed}} = 1/1.0002 = .99980004$
SUM		1.0002	

The weights make up the slope of the indifference curve or $-U_{\text{speed}}/U_{\text{capacity}}$.

3. Determination of the Quality Ratios

The weights can now be used to determine the Effectiveness Index. The characteristics of each ship is considered representative of its fleet and is used in the calculation.

Fast Ship Fleet:

$$\begin{aligned}EI &= (.00019996) * 12 \text{kft}^2 + (.99980004) * (20) \text{days} \\&= 2.395 + 19.999 \\&= 22.399\end{aligned}$$

Slow Ship Fleet:

$$\begin{aligned}EI &= (.00019996) * 15 \text{kft}^2 + (.99980004) * (10) \text{days} \\&= 2.999 + 9.998 \\&= 12.997\end{aligned}$$

The Effectiveness Index can now be used to determine the Quality Ratio. In Section 3 the Quality Ratio for a ship was defined as the Effectiveness Index divided by the total relevant cost of the ship or: $QR = EI/C$. For the Fast Ship Fleet, the Quality Ratio would be:

$$\begin{aligned}QR_{\text{fast}} &= 22.399 / (35,000,000) \\&= 6.399 \times 10^{-7}\end{aligned}$$

The Quality Ratio for the Slow Fleet can be computed as follows:

$$\begin{aligned}QR_{\text{slow}} &= 12.997 / (30,000,000) \\&= 4.332 \times 10^{-7}\end{aligned}$$

Note that the cost used to determine the Quality Ratios is the costs considered relevant to the fleets. Acquisition costs were not included in the analysis. The results of the analysis is that the fast ships are the most effective to activate in a time of crisis given policy makers' preferences.

The ships are activated with-in the constraint of a \$250 million budget. The cost of activating all five of the fast ships is \$35M times 5 or \$175M. Therefore, \$75M remains unspent. Two additional ships of the slow class may be purchased. The total amount of capacity activated is $(12,000 \text{ ft}^2 * 5) + (15,000 \text{ ft}^2 * 2) = 90,000 \text{ ft}^2$. The total cost of activation is $(\$35\text{M} * 5) + (\$30\text{M} * 2) = \$235 \text{ million}$. The speed and capacity of the combination of ships is optimal given the preferences of the decision maker.

I. EXAMPLE 2. (OPTIMAL CHOICE FOR FLEET ADDITIONS)

1. Determination of Production Possibilities Curve

The production possibilities curve of fleet additions is determined from the data given in Example 1. In this example the relevant cost for one ship of the Fast Fleet is \$133 Million and for the Slow Fleet it is \$80 Million. The total budget that can be spent on the new sealift ships (\$400M) can therefore purchase and support three ships of the Fast Ship type or five ships of the Slow Ship type. Figure 8 shows the production possibility for the new purchase.

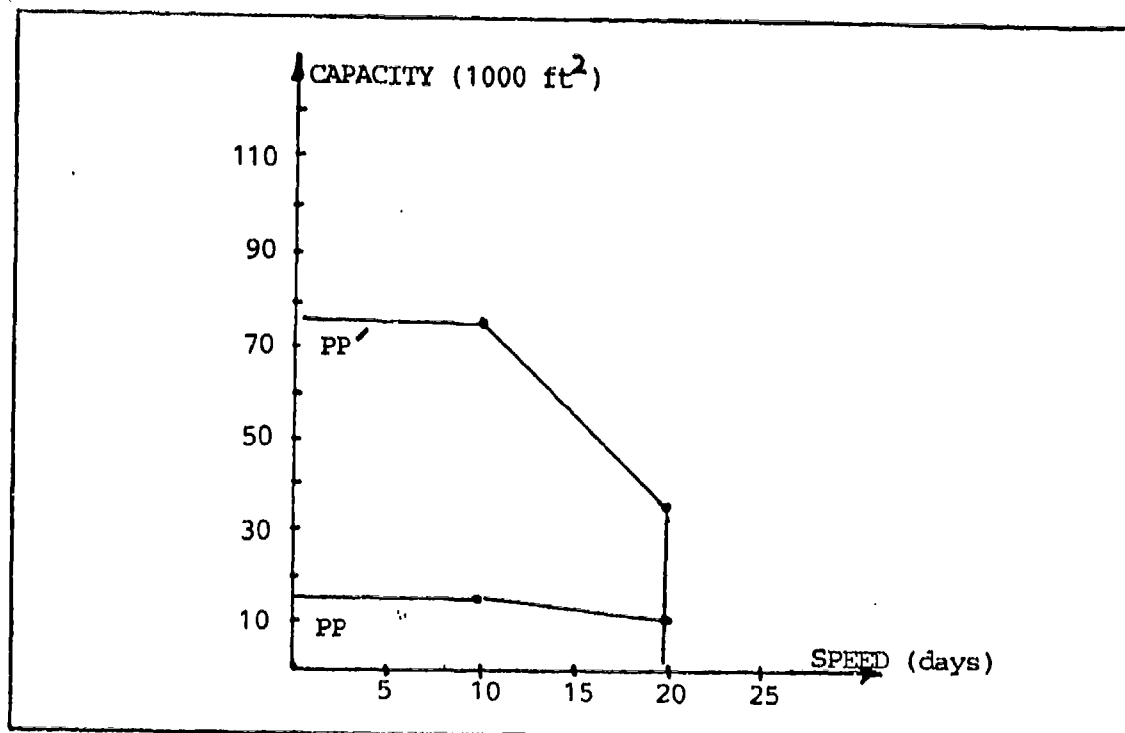


Figure 8. Additional Ship Production Possibility

Again, the single ship production possibilities is designated by PP while the production possibilities for the entire fleet that can be purchased is designated by PP'.

2. Determination of Indifference Curve

The Indifference curves of the additional ships can are the same as those for Example 1.

3. Determination of Quality Ratios

The Effective Indices can be determined for each of the fleets:

Fast Ship Fleet

$$\begin{aligned}
EI &= (.00019996) * (12,000 * 3 \text{ ft}^2) + (.99980004) * 20 \text{ days} \\
&= 7.199 + 19.996 \\
&= 27.195
\end{aligned}$$

Slow Ship Fleet

$$\begin{aligned}
EI &= (.00019996) * (15,000 * 5 \text{ ft}^2) + (.99980004) * 10 \text{ days} \\
&= 14.997 + 9.9980004 \\
&= 24.995
\end{aligned}$$

The Quality Ratios of the different fleet additions are now computed:

$$\begin{aligned}
QR_{\text{fast}} &= 27.195 / 400M = 6.799 \times 10^{-8} \\
QR_{\text{slow}} &= 24.995 / 400M = 6.249 \times 10^{-8}
\end{aligned}$$

The Fast Ship additions is therefore the most effective choice of policy makers given a limited budget of \$400 million.

J. CONCLUSION

A model for optimizing sealift fleets has been developed. First, options were specified for subsequent optimization. Once the options were specified, costs of the options were discussed. The relevant costs were then determined by examining the life-cycle of sealift ships. Once the relevant costs were determined an optimization model was developed that considered the choices of decision makers. Cost and time models were then determined for use

in the optimization model. Finally, procedures were given for optimizing the options selected at the beginning.

IV. MULTIPLE TRIP MODEL

A. INTRODUCTION

Optimization models for single trip mobilizations were developed in Chapter III. The models in Chapter III were developed for sealift ships that mobilized and performed a one trip mission. It was assumed that once the ship delivered its goods that its mission was complete. If sealift ships are intended to make multiple trips (i.e. deliver, return, reload, deliver, etc.), then the additional trips should be considered in determining the effectiveness of the ships. This chapter will extend the cost and time concepts developed in Chapter III to derive models for multiple trips. As in Chapter III, the models are developed for two options: 1. the status quo and 2. fleet additions.

B. COST AND TIME MODELS

1. Option 1

a. RRF

(1) Costs. A cost model for multiple trip mobilizations in the RRF can be developed along the same lines as in Section G of Chapter III. As in Chapter III, the measurement of dry cargo capacity should be in units of ft, and tanker capacity is measured in the units of tons.

1. Maintenance Costs: Similar to the single trip model, the maintenance costs of the RRF are a stream of future costs for

maintaining each ship. The cost of maintenance for each year must be multiplied by a discount rate to standardize the payments to the current year. The maintenance cost of the n th Option 1 RRF ship is modeled by Cn_{maint} where:

$$Cn_{\text{maint}} = \text{Sum}[Cn_{\text{yr1}}(f_1) + Cn_{\text{yr2}}(f_2) + \dots + Cn_{\text{yrM}}(f_M)]$$

and the term f_m is the discount rate factor for the m^{th} year in the future that the RRF ship is maintained.

2. Activation Costs: Similar to the single trip model, the cost of activating the n^{th} RRF ship is modeled by the term Cn_{act} .

3. Operational Costs: The operating costs of the multiple trip model are the most changed in comparison to the single trip model. The operation of the ship is now more extensive. Again, the operating costs take into consideration the loading, steaming, and unloading of the ship. Here, though, the ship may be loaded, sailed, and unloaded two or more times. The total cost of the n^{th} ship for the multiple trips and the subsequent loading and unloading is modeled by the term $\text{Sum}[Cn_{\text{RTop}}]$.

4. Manning Costs: The costs to man the n^{th} ship is modeled as Cn_{man} .

5. Redactivation: Once the ship has completed its mission it must be deactivated and prepared for the next contingency. This deactivation is subsequent to the original deactivation that placed

the ship into the RRF. Again, the deactivation costs for the n^{th} ship are modeled by the term Cn_{redact} .

The total costs associated with a multiple trip for the n^{th} ship in the RRF can now be modeled as:

$$Cn_{\text{tot}} = Cn_{\text{maint}} + Cn_{\text{act}} + \text{Sum}[Cn_{\text{RTop}}] + Cn_{\text{man}} + Cn_{\text{redact}}.$$

(2) *Time.* The time that a multiple trip RRF ship takes to perform its mission is significantly changed from the single trip model. Here the time of subsequent trips must be considered. As in the single trip model, the time of the final return trip should not be considered because ship has completed its mission once it unloads the last time. The total multiple trip time for the n^{th} ship can be modeled as:

$$Tn_{\text{tot}} = Tn_{\text{act}} + Tn_{\text{man}} + \text{Sum}[T_{\text{RTop}}] - Tn_{\text{return}}$$

where Tn_{act} , Tn_{man} , Tn_{return} is the time to activate, man, and return the ship after the final unloading respectively. The term $\text{Sum}[T_{\text{RTop}}]$ is the round trip operating times consisting of the sums of the round trip loading, steaming, and unloading times.

$$\text{Sum}[Tn_{\text{RTop}}] = \text{Sum}[Tn_{\text{load}}] + \text{Sum}[Tn_{\text{sta}}] + \text{Sum}[Tn_{\text{unload}}]$$

b. MPS

The model for prepositioned ships may be determined along the same lines as the RRF model. Because prepositioned ships

carry a variety of liquid and dry cargo, the effectiveness of the ships is measured by tons per day delivered. The unit of capacity used in the Effectiveness Index is therefore tons.

(1) Costs

1. Maintenance Costs: As in the single trip model, the cost of manning is included in the maintenance because of its peace-time manning. The maintenance costs would also include rental fees for anchorage sites. The maintenance costs of the n^{th} ship are modeled by the term Cn_{maint} , where:

$$Cn_{\text{maint}} = \text{Sum}[Cn_{\text{yr1}}(f_1) + Cn_{\text{yr2}}(f_2) + \dots + Cn_{\text{yrM}}(f_M)].$$

Again the term f_m is the discount rate factor for the m^{th} year in the future that the prepositioned ship is maintained.

2. Activation Costs: As in the case with the RRF, the term Cn_{act} is used to represent the cost to activated the n^{th} ship in the prepositioned force.

3. Operating Costs: The cost of operating is the most changed in the multiple trip model compared to the single trip model. Here the cost of the first leg is to the war zone. Once the ship has unloaded in the war zone, it must travel to the continental United States for further loading. The total operating costs also include the final loading and return to the original anchorage site. The round trip operating costs are modeled by the term Cn_{RTop} .

4. Deactivation Costs: Once the ship has returned to its original anchorage site it will be deactivated. Although deactivated, the ship remains manned and in a much higher readiness level than RRF ships. The deactivation costs for the n^{th} ship are modeled by the term Cn_{deact} . The total cost for the n^{th} ship is then modeled as:

$$Cn_{\text{tot}} = Cn_{\text{maint}} + Cn_{\text{act}} + Cn_{\text{RTop}} + Cn_{\text{deact}}.$$

(2) Time. The time relevant to a prepositioned ship is the time from being called into service to the time after its last unloading. The time that the ship takes to make the original trip to the war zone and unload is modeled by the terms T_{stm} and T_{unload} respectively.

The time for the total of each subsequent round trip is modeled by the term $\text{Sum}[T_{\text{RTop}}]$ where:

$$\text{Sum}[T_{\text{RTop}}] = Tn_{\text{act}} + \text{Sum}[T_{\text{RTstm}}] + \text{Sum}[T_{\text{RTload}}] + \text{Sum}[T_{\text{RTunload}}].$$

Here $\text{Sum}[T_{\text{RTstm}}]$, $\text{Sum}[T_{\text{RTload}}]$, and $\text{Sum}[T_{\text{RTunload}}]$ are the total steaming, loading, and unloading times respectively, in trips subsequent to the first to the war zone.

2. Option 2

As in Option 1, the measure of effectiveness should coincide with the type of ship and fleet for which the ship is being acquired. Ships types with dry cargo will use the measure of

effectiveness of ft^2/Day , thus their unit of capacity used in the Effectiveness Index is ft^2 . For ship types that carry liquid cargos, the unit of capacity is tons.

a. RRF

(1) Costs. The cost of fleet additions is similar to the cost for Option 1 with the addition of the purchase costs and the original deactivation costs which place the ship in the RRF. As in Chapter III, the purchase costs and the original deactivation and storage costs for the n^{th} ship are modeled by the terms Cn_{purch} and Cn_{DSt} respectively. The total costs of an additional ship in the RRF is modeled by:

$$Cn_{\text{tot}} = Cn_{\text{pur}} + Cn_{\text{DSt}} + Cn_{\text{maint}} + Cn_{\text{act}} + Cn_{\text{man}} + \text{Sum}[Cn_{\text{RTop}}] + Cn_{\text{redac}}$$

where Cn_{act} , Cn_{maint} , Cn_{man} , $\text{Sum}[Cn_{\text{RTop}}]$, and Cn_{redac} is the same as defined in Alternative 1.

(2) Time. The time that a fleet addition takes to perform its mission is the same as those ships already in the fleet. The total time to perform the mission is modeled by the terms:

$$T_{\text{tot}} = T_{\text{act}} + T_{\text{man}} + \text{Sum}[T_{\text{RTop}}] - T_{\text{ret}}$$

The terms are exactly the same as those defined in Option 1.

b. MPS

(1) *Costs.* Fleet additions to prepositioned forces must include the purchase and original deactivation and storage of the ship at its prepositioned site. The costs are modeled in the exact same way as in Alternative 1. The total costs with the purchase and deactivation and storage terms is modeled as:

$$Cn_{tot} = Cn_{purch} + Cn_{dst} + Cn_{maint} + Cn_{act} + Cn_{RTop} + Cn_{redact}$$

(2) *Time.* The time that should be used in the Effectiveness Index is exactly the same as that for Option 1.

C. CONCLUSION

The method for the optimal use of the fleets will be the same as that given in Chapter III. The model in this chapter may be used if multiple trips by sealift ships are expected. If only one trip is necessary then the model developed in Chapter III may be used.

V. CONCLUSION

A. RESULTS

The research in this paper has produced three significant points. The first is that decision makers should include their preferences of capacity and speed in decisions about sealift fleet components. Another result is that significant benefits may be achieved by making changes in the accounting practices for sealift expenditures. Also, the optimal fleet may be a combination of ships with various mixes of the characteristics of speed and capacity. Each of the results is discussed below.

The preferences of speed and capacity is a significant element in the determination of an optimal mix of sealift ships. Without knowing what trade-offs the decision maker would be willing to make, a choice of a fleet of ships would tend to fulfill either, but not optimally. By deciding upon a fleet of ships that either fulfills a capacity requirement or a speed/time requirement, significant preferred capability is being ignored and wasted.

Significant savings seem to be achievable by changes in the accounting practices of the Maritime Administration and the Strategic Sealift Command. The current practice of grouping expenditures into appropriation accounts and major ship types is too broad for their use in an optimization model of the sealift fleet. Collection of RRF maintenance/equipment replacement

expenditures by individual hull/ship would increase the ability to assess the value of the sealift fleet. Decisions based on "expected effectiveness" (Chapter III, E.3) and future RRE acquisitions could be accomplished with greater knowledge of the individual ship's contribution to naval sealift. This appears to be a minor change to the Maritime Administration accounting system since the maintenance work is accomplished by ship hull.

The model also points out that an optimal mix of sealift ships may consist of a combination of ships with various mixes of the characteristics of speed and capacity. The decision maker should first select those ships that lie on the indifference curve and the production possibilities curve. If the number of ships at this "most preferred point" is insufficient, then the decision maker moves to a lower indifference curve.

It may be that the next available type of ship along the production possibilities curve is high in capacity and low in speed. If after selection of this second type the requirements are still not satisfied, then the decision maker moves to an even lower indifference curve. The lower indifference curve may include ships that have the characteristics of high speed and low capacity.

The point is that given the trade-offs that a decision maker is willing to make regarding sealift ship types, a combination of different ships may fulfill his requirements and his preferences. The goal is to obtain and activate those ships that provide the

best efficiency while considering the preferences of the decision maker (slope of the indifference curve).

B. RECOMMENDATIONS

When comparing fleet types using the Quality Ratio it should be noted that the comparison is between ratios. Ratios may be misleading especially if there are bands of uncertainty around capabilities or costs.

Similarly, since the determination of a best mix is accomplished with numbers, there is an opportunity to change the numbers after the fact. For example, should a ship selection be unsatisfactory (based on the quality ratios), the assumptions and considerations of decision maker preferences may be easily changed to provide a more desired result. It is important not to deviate from the original preference data in order to insure consistent results.

Also, the Quality Ratio should only be used as a tool for the selection of sealift fleets. Other considerations not included in the analysis may be sufficient to over-ride the selection calculated with the Quality Ratios. Other considerations not included in the analysis may be the ship construction industry, the size and category of indirect costs, the availability of qualified personnel to operate sealift ships, and the availability of adequate storage and activation facilities for the RRF.

C. FUTURE RESEARCH EFFORTS

Research efforts should be taken to prove the models provided in Chapters III and IV. Considerable data is available at the Military Sealift Command and the Maritime Administration that may be collected and used in an analysis. Also, a study of the indirect costs of military sealift should be done in order to verify the assumption that they do not significantly affect the results of the analysis.

APPENDIX A. CALCULATION OF RELATIVE WEIGHTS

One way to determine U_{capacity} and U_{speed} is to elicit the values of speed and sealift from policy makers. Questions may be asked of the relative importance of an amount of capacity compared to an amount of speed. Note that here the term "speed" is the relative quickness of a sealift mode. It is not measured in the parochial units of distance/time, but is a measurement of time alone. A measure of speed is therefore the amount of time that it takes a ship to perform its task. The measurement of time from some standard is used. Therefore ships quicker than the standard would increase their Effectiveness Index while ships that are slower than the standard would decrease their Effectiveness Index.

Let C_c be a relative amount of speed that a policy maker would be willing to trade for given amount of capacity. The following procedure can be used. The relative weights a and b can be calculated by dividing the second column of values by the sum of the values. [Ref. 21:pg. 8] Table 1 displays the steps that are performed to obtain the weighted values.

	CAPACITY	SPEED	weights	
	1	Cc	$U_{capacity} = Cc/Sum$	where
			$Sum = 1 + Cc$	
	1/Cc	1	$U_{speed} = 1/Sum$	
		Sum		

Table A1. Calculating Weights

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